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LOCATION SWANSEA

LLEOLIAD ABERTAWE

LEVEL 6

LEFEL 6

EXAMINATION PERIOD

CYFNOD ARHOLIADAU

MAY 2020

MAI 2020

MODULE CODE: M6X00410
Competition Engine Design

TIME: 2 HOURS

ANSWER THREE QUESTIONS OUT OF FOUR

Note that in all your answers, marks will be awarded for detailed explanation of the calculation steps. It is essential to include explanations.

QUESTION ONE

You are required to carry out the balancing of a horizontally mounted 500 cc in-line twin cylinder range extender engine at first order of crankshaft rotation. The crankshaft is single plane with both cylinders at TDC simultaneously. The engine will be installed horizontally in the rear of the car under the boot floor

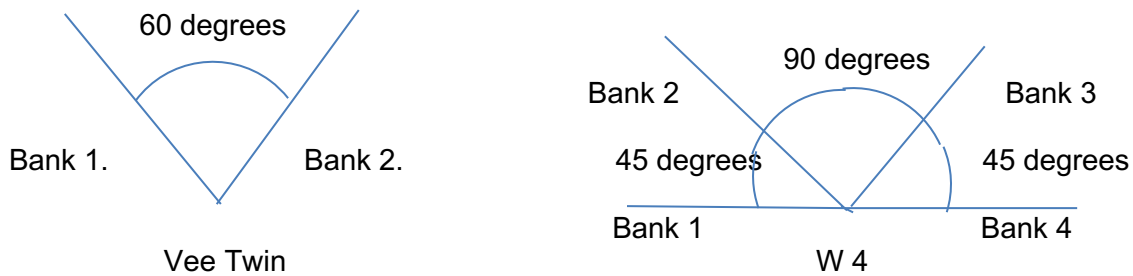
Assume a piston and gudgeon pin with a total mass of 240 gms. Assume a forged steel con-rod of total mass of 330 gms. Assume that the big-end bearing shells have a total mass of 20 gms. Assume that the stroke is 90 mm. Assume that the crankshaft is made of steel and has a mass of 5.0 kg. Assume a con-rod length of 140mm.

- (a) Using diagrams, and fully explaining the physics, calculate the total mass moment of the resultant first order forward rotating vector acting on the crankshaft as a result of the reciprocating and rotating forces from the piston/connecting rod assemblies. Give your answer in kg.mm.
(2 marks)
 - (b) Explaining fully the reasons, calculate the required offset in mm of the crankshaft centre of mass from its centre-line of rotation to fully balance the calculated forward rotating vector in part (a). Sketch the crankshaft to illustrate your answer.
(2 marks)
 - (c) Calculate the mass moment in kg.mm of the first order reverse rotating vector.
(2 marks)
 - (d) The reverse rotating first order vector is also to be fully balanced for its hybrid car application. Would you drive the balance shaft from the crankshaft with gears, chain or belt? Sketch a schematic drawing of the drive mechanism of your choice looking at the front of the engine.
(2 marks)
 - (e) Assuming the balance shaft has a total mass of 2.5 kg, calculate the required offset in mm of its centre of mass from its centre-line of rotation to fully balance the reverse rotating first order vector.
(2 marks)
 - (f) If the crankshaft has rotated clockwise 210° from top-dead-centre, show where the eccentric part of the balance shaft should be pointing. Use a sketch of front view of the engine to illustrate your answer.
(2 marks)
 - (g) For markets where a balance shaft will not be used for cost reasons, explain the balancing strategy you will use for the crankshaft to minimise vertical car vibrations, using diagrams to support your reasoning. Calculate the required mass moment of the crankshaft in kg.mm.to fulfil your strategy.
(4 marks)
 - (h) For a luxury car edition the engine will also be fitted with twin additional balance shafts to minimise second order engine vibrations. Explain how you would implement this strategy and calculate the mass moment of each of the required balance shafts.
(4 marks)
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QUESTION TWO

You are required to understand the balancing of a 60° Vee Twin Engine and then develop the analysis for a W4 Engine. For the Vee Twin, assume both conrods share a common crankpin. For the W4 Engine, assume all four rods share a common crankpin and that the angle between the centre banks is 90° .

The schematic diagrams below show the layout of the two engines:



For both engines, assume the following specification:

Piston Mass	=	240 gms
Conrod Mass	=	360 gms
Stroke	=	80 mm
Conrod Length	=	140 mm

For all the questions below, use a suitable sketch to show your answer and fully explain the principles.

- For the Vee Twin Engine, put the crankpin along Bank 1 and calculate the magnitude and direction of the resultant first order forward rotating vector. Express the magnitude as a mass moment in kg.mm. (1 mark)
- Again, for the Vee Twin Engine with the crankpin along Bank 1, calculate the magnitude and direction of the resultant first order reverse rotating vector. Express the magnitude as a mass moment in kg.mm. (2 marks)
- For the W4 Engine, put the crankpin along Bank 2 and calculate the magnitude and direction of the resultant first order forward rotating vector. Express the magnitude as a mass moment in kg.mm. (1 mark)
- For the W4 Engine, put the crankpin along Bank 2 and calculate the magnitude and direction of the resultant first order reverse rotating vector. Express the magnitude as a mass moment in kg.mm. (2 marks)
- Explain how you would balance these first order forward and reverse rotating forces in a real engine application. (2 marks)
- If the crankpin rotates clockwise 135° from bank 2 show the position of the resultant first order reverse vector using a suitable schematic diagram. (2 marks)

- (g) For the W4 Engine, put the crankpin along Bank 1 and calculate the magnitude and direction of the resultant second order forward rotating vector. Express the magnitude as a mass moment in kg.mm. (3 marks)
- (h) For the W4 Engine with the crankpin again along Bank 1 calculate the magnitude and direction of the resultant second order reverse rotating vector. Express the magnitude as a mass moment in kg.mm. (3 marks)
- (i) Combine the individual forward and reverse second order resulting forces calculated above to determine the total resultant second order force and state which direction it lies in. Analysing the resultant second order force carefully, does its direction change as the crankshaft rotates? Use a diagram to explain. (4 marks)

QUESTION THREE

You are required to develop balancing strategies for an inline 5 cylinder engine as installed in a Ford RS Focus or Volvo. The angle between crankpins is 72 degrees.

You are required to look at a local balancing strategy and a lighter weight global balancing strategy. The engine specification is as follows:

Piston Mass	=	240 gms
Conrod Mass	=	270 gms
Stroke	=	85mm
Conrod Length	=	140 mm
Crankpin Phasing	=	72°

The figure below shows the crankpin arrangement looking from the front of the engine. All cylinders are equally spaced with a distance between cylinder centres of 92mm.

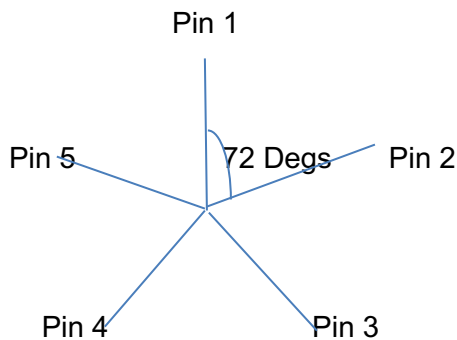


Figure Crankpin configuration looking from engine front.

Part 1 - Local Balancing

- (a) Calculate the mass moment in kg.mm. of the effective first order forward rotating vector acting at the centre of each crankspan. (2 marks)
- (b) If each crankspan of the crankshaft has a mass of 3.0 kg, calculate the required local centre of mass offset in mm needed to achieve 100% local balance. (2 marks)
- (c) Make a sketch from the front of each crankspan, showing the offset centre of mass obtained in part (b) and explain mathematically why bolt-on tungsten counterweb masses can reduce the overall moment of inertia of the crankshaft whilst maintaining the same balance. Why is this important for racing engines? (2 marks)

Part 2 - Global Balancing

For a particular racing application, it is now required to minimise all counterweights to reduce the crankshaft mass and achieve the required balancing through an out-of-balance front pulley and flywheel.

In order to achieve sufficient local balance for main bearing life two symmetrical counterweights will be introduced for each of the 5 cranks to achieve a local balance at each crankspan of 50% of the total forward rotating vector at that span.

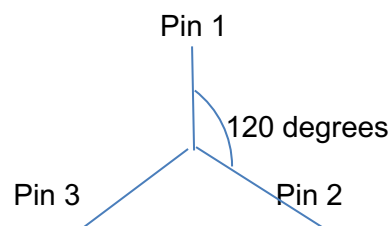
- (a) Calculate the magnitude of the resultant moment of the first order forward mass moments acting along the entire crankshaft. Express your answer in kg.mm.mm.
(7 marks)
- (b) Looking from the front of the engine (ie. view from the front), draw a sketch showing the angle (with calculation proof) of the resultant forward moment of the first order mass moments relative to crankpin 1.
(3 marks)
- (c) With the same view from the front, show where the direction of the required centres of mass of the pulley and flywheel need to be to achieve overall first order forward rotating balance.
(2 marks)
- (d) Assuming a distance of 480mm between the centre of masses of the front pulley and flywheel calculate the required mass moment of the flywheel in Kg.mm needed to achieve full first order forward balance of this engine.
(2 marks)

QUESTION FOUR

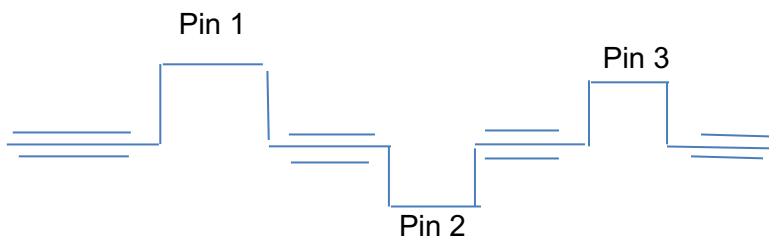
You are required to carry out a second order analysis on an in-line 3 cylinder engine. The engine is vertically mounted and the crankpins equally phased at 120 degrees to one another.

The engine has internals with the following specification:

Piston Mass	=	240 gms
Conrod Mass	=	300 gms
Conrod Length	=	150 mm
Stroke	=	90 mm
Cylinder bore spacing distance	=	100 mm



View from Front with Pin 1 at TDC



View from side with Pin 1 at TDC

- (a) With Pin 1 at TDC calculate the magnitude and direction of the forward rotating second order mass moments of each cylinder. Use a view from the front similar to the question drawing to show your answer. What is the resultant of these mass moments? (2 marks)
- (b) With Pin 1 at TDC calculate the magnitude and direction of the reverse rotating second order mass moments of each cylinder. Use a view from the front similar to the question drawing to show your answer. What is the resultant of these mass moments? (2 marks)
- (c) In a similar way to First Order balancing calculate the resultant moment of the forward rotating second order mass moments by calculating the moments of the mass moments in both the plane of pin 1 and perpendicular to the plane of pin 1 when pin 1 is vertical at TDC. Give your answer in Kg.mm (4 marks)

- (d) Calculate the angle of the resultant moment of the forward second order mass moments relative to pin 1 when pin 1 is at TDC. Show the direction of the resultant moment of the second order forward mass moments using a view from the front. (2 marks)
- (e) If Pin 1 rotates clockwise by 90 degrees calculate the new angle of the resultant moment of the forward second order mass moments relative to Pin 1. Use a diagram with view from front to show your answer. (3 marks)
- (f) Calculate the angle of the resultant moment of the reverse rotating second order mass moments relative to Pin 1 when Pin 1 is at TDC. Show the resultant direction using a view from the front. (2 marks)
- (g) If Pin 1 rotates clockwise by 90 degrees calculate the new angle of the resultant moment of the reverse second order mass moments relative to Pin 1. Use a diagram with view from the front to show your answer. (2 marks)
- (h) Does the overall resultant moment of the second order mass moments rotate or stay in a fixed plane? Fully explain your answer. (3 marks)